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Neolithic human impact on landscapes related to megalithic structures: palaeoecological evidence from the Krähenberg, northern Germany

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ABSTRACT

New aspects of prehistoric forest use and human activities around megalithic graves were inferred from a palaeoecological study at Krähenberg, northern Germany. Five megalithic graves of the Funnel Beaker Culture are located very close, i.e. ca. 100 m south-west of a small mire which was investigated for pollen and charcoal records. This unique situation provides a detailed reconstruction of the local vegetation development and fire history for the area surrounding the megalithic graves, by investigating a peat core sequence, and backed by 11 AMS ^{14}C measurements and archaeological data. The deciduous forests experienced a slight reduction in the canopy around 3500 cal. BC, suggesting an increased but weak human impact, possibly associated with the construction of the megalithic graves. Following the period of anthropogenic activity, forest recovery occurred over a period of about 400 years. Our results suggest that the designated site was isolated from settlements and arable fields during the Neolithic period. The graves were imbedded in a woodland landscape. Although forest disturbance occurred during the Neolithic period, intense human impact associated with arable farming first commenced during the Bronze Age.

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1. Introduction

Recent archaeological and radiocarbon investigations of megalithic structures in northern Germany and southern Scandinavia indicate that most of the megaliths in these regions were constructed during a comparatively short time period. The construction period ranged from the late Early Neolithic to the Middle Neolithic ~3500–3000 cal. BC, during the period of the Funnel Beaker Culture ~4100–2800 cal. BC (Müller, 2011). It is assumed that about 25,000 large stone tombs were built in the North European Plain during the fourth millennia BC (Zich, 2009). The most important periods of those constructions can be narrowed to ~3500–3200 cal. BC (Persson and Sjögren, 1995; Rasmussen and Bradshaw, 2005). The appearance of megaliths is an indication of new complex social and religious organisational systems (Müller, 2010; Sherratt, 1995) and they reflect the evolution of the relationship between humans and nature. Most of them were erected on the top of hills, thus being positioned at an important viewpoint within the landscape. Therefore, this often dominant topographical position of the monuments led to the assumption that the surrounding woodland must have been permanently opened, in order to make the monuments visible from the surrounding landscape (Cummings and Whittle, 2003; Tilley, 2010) in connection with the construction and use of the megalithic graves (Andersen, 1992).

However, the relationship between megaliths and their surroundings, with the woodlands, cultivated fields and settlements, is not fully understood. The level and intensity of woodland clearance is not known, and it is unclear whether megalithic graves were integrated into the agricultural landscape or separate segregated places, presumably reserved for ritual or cultic purposes. Knowledge about their environmental setting during the Neolithic is especially lacking. Moreover, it is impossible to answer these questions based only upon archaeological evidence, thus, making an interdisciplinary approach necessary. Several recent studies show the organisational complexity of Neolithic landscapes with a differentiation into farming areas, settlements, and burial sites.

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The so-called 'landscape openness' hypothesis, is intensively discussed for the Bronze Age burial monuments (Dreibrodt et al., 2009; Hannon et al., 2008), and can be rejected in some cases for the megalithic graves. Investigations from Denmark (Andersen, 2010) and Sweden (Axelsson, 2010; Sjörgren, 2010) point towards the spatial and visual separation of the tombs from settlements and cultivated areas in the landscapes of the Funnel Beaker Culture. According to pollen evidence from a Late Neolithic stone cist in southern Sweden, Lagerås (2000) concluded that flowers were ritually deposited in the area, and a semi-open woodland with pasture and small-scale cereal fields surrounded the site. The investigation of Neolithic monuments in Netherlands has revealed evidence of ritual activity, inside and outside the graves (Wentink, 2006). In Germany, multidisciplinary studies in the Altmark region (Demnick et al., 2008) indicate numerous ritualistic activities together with a continuous forest coverage of the megalithic tomb and its immediate surroundings during the vast majority of the Neolithic period.

In this paper, we used palynology together with micro- and macrocharcoal quantification to reconstruct the environmental and vegetational changes of the surrounding area of five megalithic graves of the Funnel Beaker Culture, which are located at the top of Krähenberg-Hill in Schleswig-Holstein, northern Germany. These megalithic graves are located close (100–400 m) to the investigated small mire at Krähenberg within its relevant pollen source area (Sugita, 1994).

Small mires and lakes are valuable archives to trace environmental and vegetational changes within their immediate vicinity (e.g. Davies and Tipping, 2004; Fyfe et al., 2003; Rickert, 2006). Our hypothesis was that Neolithic people cleared the surrounding woodland area at the top of a hill for the erection of these monuments, as well as for the visibility of these five megaliths, which form a prominent line in the landscape. Another aim of this study was to investigate the relationships between the presence of megaliths and cereal cultivation, as well as changes in forest composition at the study site during the Neolithic period and Bronze Age.

2. Study site

The study site of Krähenberg (Crows Hill) is located in northern Germany 2 km south of Lake Westensee in the federal state of Schleswig-Holstein, northern Germany. Land depressions along the Weichselian moraine landscape (Piotrowski, 1991) contain a multitude of lakes and kettle hole mires (Dierssen, 2005) with very good conditions for the preservation of organic material (Rickert, 2001). Cambisols and luvisols are the dominating soil types in the area (Kielmann, 1996). Currently agricultural fields and planted conifers dominate this landscape, although closed woodlands with common beech (*Fagus sylvatica* L.) still gain a significant presence. Regional land use and settlement history is known basically from archaeological (Aner et al., 2005) and historical investigations (Von Hedemann-Heespen, 1906).

Approximately 250 prehistoric sites are known within a 5 km radius around Krähenberg. Several archaeological sites from the Paleolithic ~11,000–9500 cal. BC and Mesolithic ~9500–4100 cal. BC were found in the study area (State Archaeological Department of Schleswig-Holstein 2010, unpublished data). The archaeological findings show a period of more intense human activity from the late Early Neolithic ~3500 cal. BC to early Middle Neolithic ~3300–3200 cal. BC. Neolithic sites were analysed using GIS-techniques.

(Sadovnik et al., 2012). Some of the items found were 17 megalithic graves, 9 earth-graves, 34 findings of polished flint axes and flint chisels, 4 records of flint knifes and 7 stone axes. Five megalithic graves of the Funnel Beaker Culture are located at the top of Krähenberg-Hill (54°15′36″ N, 9°54′04″ E; 66 m a.s.l.) (Fig. 1).

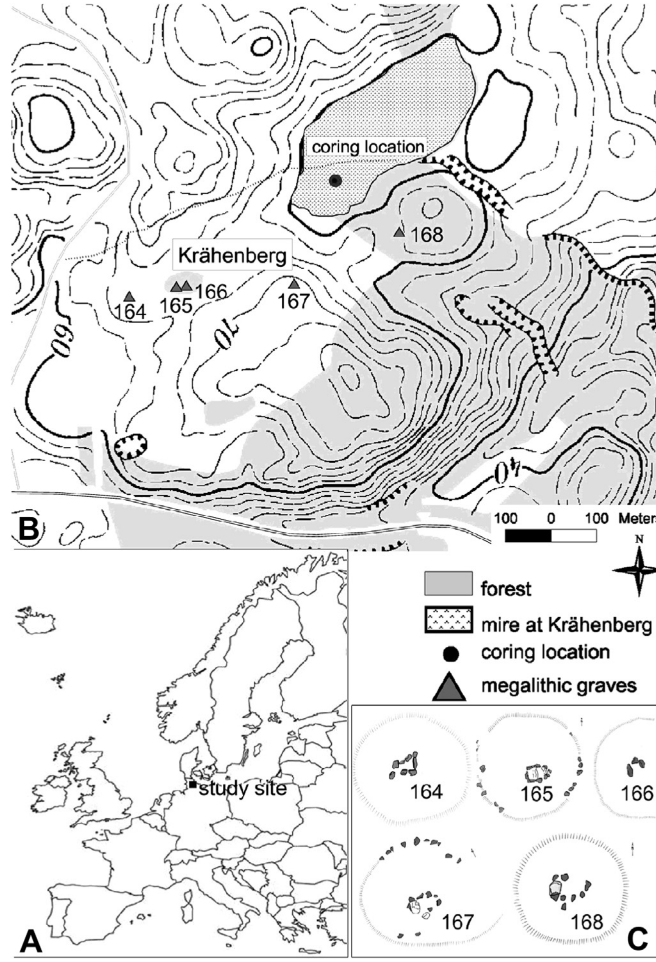

Fig. 1. A. Location of study site within Europe. B. The five megalithic graves and investigated mire at Krähenberg (54°15′40.15″ N, 9°54′10.05″ E), Schleswig-Holstein, northern Germany. C. Megalithic graves 164–168, modified after Sprockhoff (1966).

The mounds, which are arranged in a straight line, are up to 16 m in diameter and 3–4 m high. The monuments are well visible in the landscape, and were not covered with sand. The side stones of the burial chamber lay more or less open. Sprockhoff (1966) described the graves under the numbers 164–168 as three extended dolmens and two passage-graves. The graves are known by the archaeological records of State Archaeological Department of Schleswig-Holstein, but have not been investigated archaeologically until now. The results of a geomagnetic survey adjacent to the megaliths at Krähenberg are presented by Sadovnik et al. (2010). The mire 'Krähenberger Moor' is located approximately 100–400 m north-east from the five megaliths. It is c. 300 m long and 100 m wide, with an area of less than 3 ha. In the 18th century, the mire was divided into several parts, and used for peat cutting (Von Hedemann-Heespen, 1906).

3. Material and methods

3.1. Stratigraphy and radiocarbon calibration

A 5.60 m long peat core sequence KRM was retrieved in July 2009 from the western part of the mire (54°15′40.15″ N, 9°54′10.05″ E; 63 m a.s.l.) using a "Usinger" piston corer (Mingram et al., 2007). Stratigraphic features were recorded in the field and in the laboratory on cleaned core surfaces. Eleven samples (peat and wood) of the sequence core KRM 0.20–2.24 m were taken for

radiocarbon dating. The AMS-measurements were performed by the Leibniz-Laboratory for Radiometric Dating and Isotope Research, University of Kiel. As the ^{14}C calibration curve includes several plateaus and inversions, it is advantageous to roughly estimate the age–depth model for the core based on the pollen record, if possible, and select the first two or three samples expected to avoid the wider plateaus for measurement. By using an incremental sampling strategy instead of sampling at regular intervals and measuring all the samples at once, it is possible to improve the final chronology of a core (or sequence) obtained from a Bayesian model without increasing the number of ^{14}C results. Calendar year chronologies were calibrated using "CALIB rev 5.01", IntCal09 calibration dataset (Reimer et al., 2009) and calculated using OxCal 4.1.6 program deposition model (Bronk Ramsey, 2010, 2009).

3.2. Pollen analysis and loss-on-ignition

90 samples (1 cm^3) were taken from the upper 2 m of the core at 2 cm interval in most parts for pollen analysis. Pollen chemical preparation followed standard procedures (Fagri and Iversen, 1989; Moore et al., 1991). Pollen grains were counted using a light microscope with magnification 400× up to 1000×. The reference pollen collection of the Institute for Ecosystem Research, University of Kiel was used for pollen grain identification. Pollen taxonomy and nomenclature followed Beug (2004). The pollen diagram was compiled and plotted using the TILIA and TILIA-GRAPH software packages (Grimm, 2004). Percentage calculations of pollen taxa were based on the terrestrial pollen sum. A minimum of 500 arboreal pollen grains (AP) were counted in each sample. Non-arboreal pollen (NAP) were composed of shrubs, plants of the heath family (Ericales), upland herbs, cereals, and indicators of anthropogenic disturbance (Behre and Kučan, 1986). Pollen grains of Cyperaceae and wetland plants were excluded from the terrestrial pollen sum. One surface sample from the borehole location was counted. Loss-on-ignition analysis was performed on 90 samples (3 cm^3), according to the method described by Heiri et al. (2001). Organic matter and carbonate mineral content were calculated according to Dean (1974).

3.3. Micro- and macrocharcoal quantification

Microscopic charcoal particles ≥10 μm were counted on the same slides as the pollen. *Lycopodium* spore tablets (Stockmarr, 1971) were added to each sample (1 cm^3) for the estimation of microcharcoal concentration (no. cm^{-3}) (Tinner and Hu, 2003).

Macrocharcoal fragments ≥200 μm from each 1 cm^3 pollen sample were counted in Petri dishes after chemical preparation using a stereoscope with magnification up to 112×.

Additionally, peat samples (5 cm^3) from each longitudinal cm of the second half of the core were treated with sodium hypochlorite solution during 24 h, and sieved gently through a 200 μm sized mesh (Millspaugh and Whitlock, 1995). Then, for each sample, the sections larger than 200 μm were sorted with a stereo lens to keep only charcoal pieces. The samples were then digitally photographed with identical camera settings, and digitally analysed using the Scion Image Program (Scion Corporation) to obtain the number and the surface area of macrocharcoals (density slice function) (Mooney and Black, 2003). Finally the macrocharcoal concentration per samples (mm^2 cm^{-3}) and accumulation rate (CHAR; mm^2 cm^{-2} yr^{-1}) were calculated, following the age–depth model. This allowed for identification of macrocharcoal peaks (CHAR peaks), corresponding to local fire events, based on the analysis of the variability of the CHAR signal, using the program CharAnalysis 0.9 (Higuera et al., 2010).

4. Results

4.1. Peat stratigraphy and age–depth model

According to stratigraphical evidence, the upper layers of the mire are missing due to historical peat cutting. Therefore, the upper 30 cm of the core were not considered for further analysis. Below the surface, eight peat layers were identified along the 0.30–2.24 m section of the core (Table 1). Age–depth modelling is based on eleven ^{14}C AMS radiocarbon measurements (Table 2). A significant change of the peat layers from VI to VII were found. The calibrated age of the sample KIA40649 (1882–1694 cal. BC-2σ) indicates the beginning of the Bronze Age in northern Germany. Sequence calibration of AMS-data shows that during this period peat accumulation is very low, probably caused by decomposition after peat cutting and mire drainage in the 18th century. The ^{14}C concentration of the sample KIA41716 falls within the ^{14}C age plateau caused by an increase of sun (spot) activity during the Maunder minimum and by fossil fuel burning (Suess effect), so it was not possible to determine the calendar age of the sample to better than a wide range from AD 1520–1955. Thus the youngest three AMS-dates KIA41716, KIA40648 and KIA41660 were not used for the calculation of the age–depth model for the Neolithic period. In order to construct an age–depth model, weighted average estimates the probability of distributions of this calibrated age (1, 2 and 3σ regions) were calculated. Based on Bayesian-statistics, modelled ages from each sample for the Neolithic peat sequence were calculated from 4050 cal. BC to cal. 1770 BC (Fig. 2). This gave a mean sedimentation rate of 1 cm/14.4 yrs.

4.2. Pollen analysis, charcoal quantification, loss-on-ignition (LOI)

The percentage pollen diagram KRM (Fig. 3) consists of 61 pollen and 10 spore types. Eleven local pollen assemblage zones (LPAZ) were identified (Birks, 1986). The results of loss-on-ignition, micro- and macrocharcoal quantification are presented in Fig. 4. Zone boundaries are given as OxCal-modelled ages (medium ages BC of the calibrated range) according to the age–depth model. The main characteristics of the zones are summarized in Table 3.

5. Discussion

5.1. Local Neolithic vegetation history

Palynological investigations in Schleswig-Holstein, northern Germany indicate no lasting anthropogenic effect on the landscape

Table 1
Stratigraphic details of the investigated peat sections 0.20–2.24 m from the core KRM.

Layers	Depth (m)	Stratigraphic description
IX	0.30–0.20	Strongly decomposed sedge peat with *Eriophorum* and *Sphagnum*
VII	0.34–0.30	*Sphagnum* peat, *Eriophorum*-roots and well-decomposed grass-sedge peat
VII	0.66–0.34	Dark brown sedge-*Sphagnum* peat, medium decomposed
VI	0.77–0.66	Brown sedge peat with *Eriophorum* and *Sphagnum*
V	1.54–0.77	Dark brown sedge-*Sphagnum* peat, slightly decomposed
IV	1.64–1.54	Brown sedge peat with *Eriophorum*
III	1.76–1.64	Brown sedge-*Sphagnum* peat
II	1.83–1.76	Brown sedge peat with *Bryopsida* and *Sphagnum* remains
I	2.24–1.83	Light brown sedge peat with *Eriophorum*, *Oxycoccus*, wood remains, medium decomposed

Table 2
Results of AMS-radiocarbon datings of the core KRM 0.30–2.24 m (Leibniz-Laboratory for Radiometric Dating and Stable Isotope Research). 2σ calibrated with Oxcal 4.1.7 (Bronk Ramsey, 2010).

Lab. ID	Sampling site, depth (cm)	Sample type	Radiocarbon age (BP)	BC/AD cal. age (2σ)
KIA41716	KRM-38	Plant remains	255 ± 30	AD 1522–1951
KIA40648	KRM-52	Peat	2219 ± 21	BC 378–204
KIA41660	KRM-56	Peat	2930 ± 25	BC 1258–1040
KIA40649	KRM-72	Peat	3466 ± 27	BC 1882–1694
KIA40631	KRM-100	Peat	4020 ± 30	BC 2619–2471
KIA41661	KRM-128	Peat	4259 ± 30	BC 2919–2763
KIA41662	KRM-136	Peat	4425 ± 25	BC 3312–2925
KIA40632	KRM-160	Peat	4416 ± 25	BC 3264–2921
KIA41663	KRM-191	Wood (*Corylus*)	4800 ± 25	BC 3646–3525
KIA40633	KRM-200	Peat	5032 ± 31	BC 3946–3714
KIA41717	KRM-214	Peat	5010 ± 30	BC 3942–3705

during the period of Mesolithic, and a small-scale agriculture at the beginning of Neolithic around 4100 cal B.C. (Behre, 2007).

The transition from hunter-gatherer to farmer societies and the "landnam" *sensu* Iversen (1941) was interpreted as a long process of adaptation, lasting more than 1500 years (e.g. Nelle and Dörfler, 2008; Zvelebil and Dolukhanov, 1991). The woodland composition of Early Neolithic landscapes in northern Germany was characterised by an oak-dominated deciduous mixed forest, with a considerable proportion being made up of *Ulmus* and *Tilia*, while wet areas were dominated by *Alnus* carrs (Dörfler, 2001; Overbeck, 1975). High-resolution pollen regional diagrams (Glos, 1998; Wiethold, 1998; Wieckowska et al., 2012), from the large lakes and mires indicate that the first period of forest opening at regional level could be connected with human impact dates to approx. 3500 cal. BC.

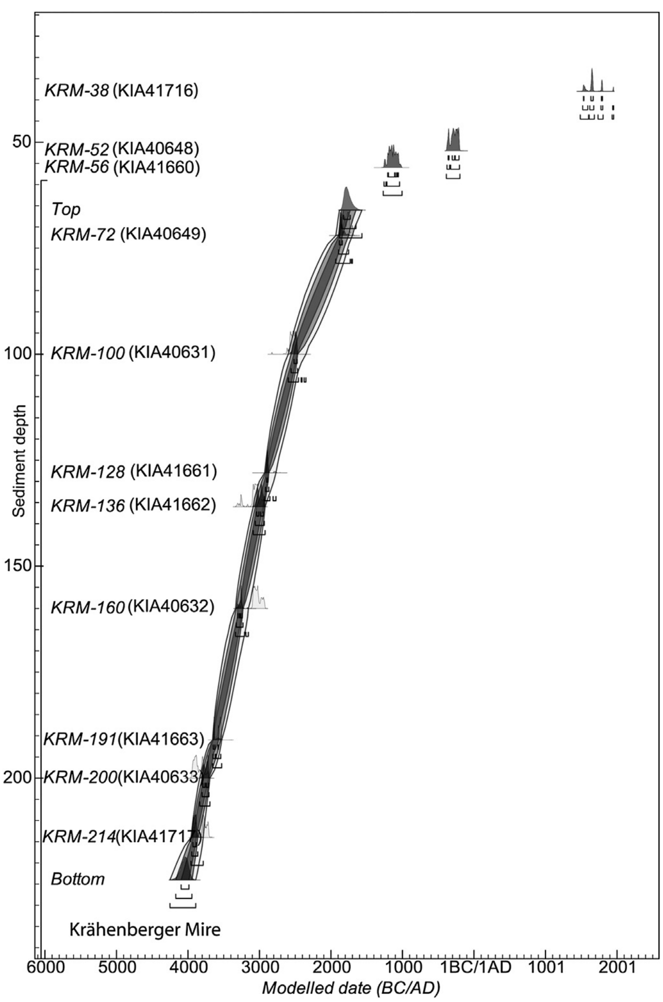

Fig. 2. Age–depth model of the core KRM 0.30–2.24 m based on eleven calibrated radiocarbon dates, respectively (OxCal, Bronk Ramsey, 2010; IntCal09, Reimer et al., 2009).

However, the analysis of peat or sediments in smaller sites with 50–100 m in diameter provide more information about the vegetation and land use history in their closest surroundings (e.g. Hellman et al., 2009; Jacobson and Bradshaw, 1981; Prentice, 1985; Sugita et al., 1999). According Sugita (1994), the pollen rain found when sampling in small sites represented for the most part the local vegetation and palaeoenvironmental development from the sites within 300–400 m of the surrounding area. The pollen diagram from the 300 m long and 100 m wide mire at Krähenberg reflects mainly the local vegetation of the area surrounding the megaliths from approx. 4000 cal. BC.

Thus, the palaeoecological investigations were designed to study the local development of the monuments and provide detailed information about the complexity of environmental change and small-scale human activity on the landscape (Fyfe, 2012), related to the megalithic graves. In contrast to the regional pollen records, the local pollen diagram from Krähenberg mire shows very low presence of anthropogenic indicators during the whole Neolithic period.

5.2. Human impact related to megaliths

The *Ulmus*-decline, a phenomena not yet chronologically fixed to a certain date on a supraregional scale (Parker et al., 2002) can be dated at Krähenberg with the most probable OxCal-modelled age around 3840 cal BC (*Zone 1*). In parallel to the *Ulmus*-decline, *Tilia* decreases possibly due to human impact. The first evidence of human activity in the landscape can be observed at Krähenberg, in the *Zone 2*, by a very slight increase of Poaceae pollen. Increase of the charcoal signals was followed by the elm decline. Remarkably high values of *Corylus* pollen from 191 cm depth might be the result of high pollen productivity after disturbances and can possibly be interpreted as the result of hazel coppicing (Göransson, 1988). Otherwise, *Corylus*, which is known of being a species with high light demand, might have dominated locally after a short opening of the deciduous forest. A *Corylus* wood fragment from this depth was AMS-dated to 4800 ± 25 uncal. BP (KIA41663) giving a calibrated date range of 3646–3525 cal. BC (2σ). The high amount of pollen from wetland plants might have been a result of the increase of surface runoff and spring activity, which furthered the wetness of the mire after the assumed short forest opening. The pollen grains of *Pinus* could be considered to have reached the study site by long distance transport (Tipping, 1989). Their increase can also be seen as a further evidence of short surrounding forest openness. This concomitance of evidence could be in connection with the construction of the megaliths. The most probable OxCal modelled ages for this period are 3651–3543 cal. BC-2σ, which gives a good agreement with the typological dating of the extended dolmens and passage-graves of the Funnel Beaker Culture ∼4100–2800 cal. BC (Müller, 2010; Schuldt, 1976; Sjögren, 2011).

It is widely known that megalithic monuments of the Funnel Beaker Culture were used for burial rituals (Hoika, 1990; Mischka, 2009). However, several recent archaeological studies have demonstrated that the megaliths were probably not primarily burial places immediately after their erection in the late Early Neolithic, and were used secondarily as collective burial places in the Middle Neolithic (Steinmann, 2009; Veit, 1993). A number of investigations indicate the phenomenon of re-using of megalithic graves during the Single Grave Culture ∼2800–2200 cal. BC

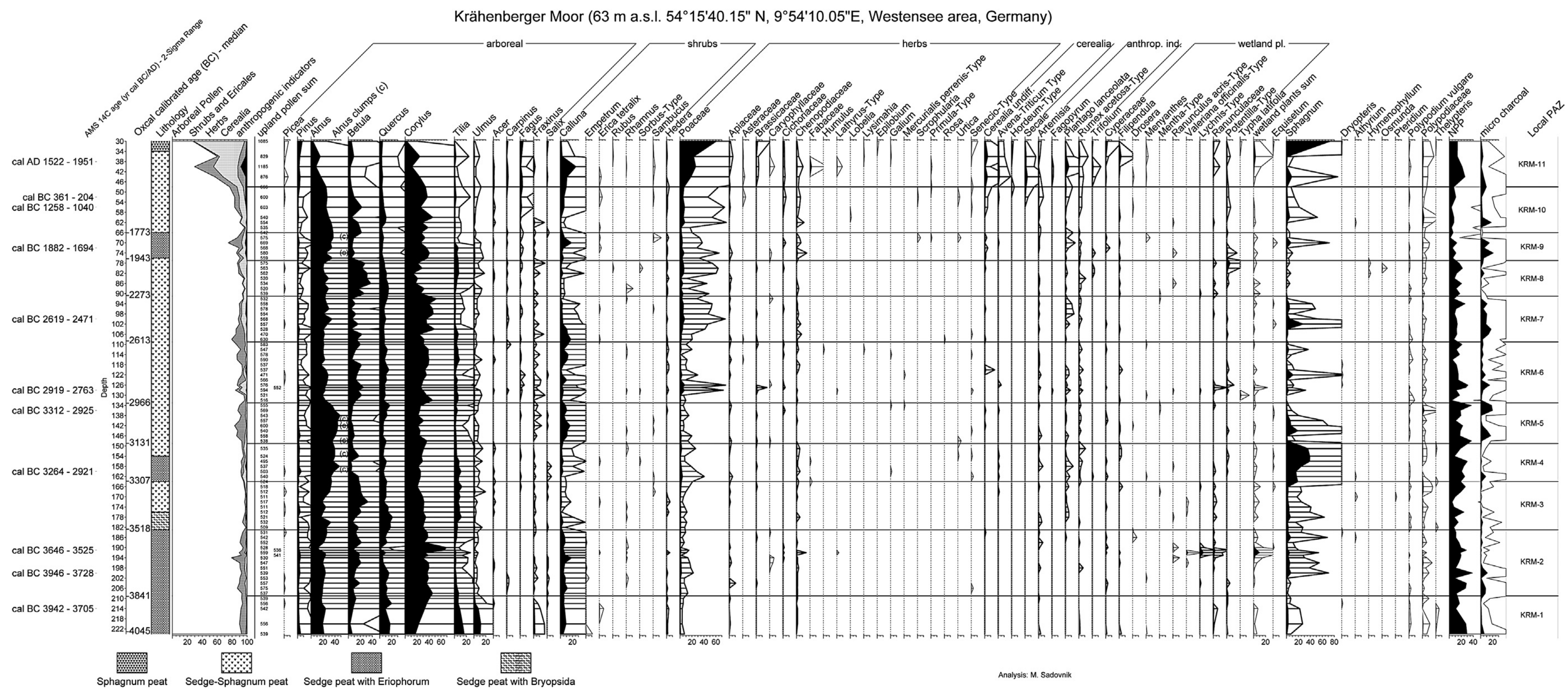

Fig. 3. Percentage pollen diagram of the core KRM 0.30–2.24 m. Values refer to the upland pollen sum. White curves are exaggerated by 10.

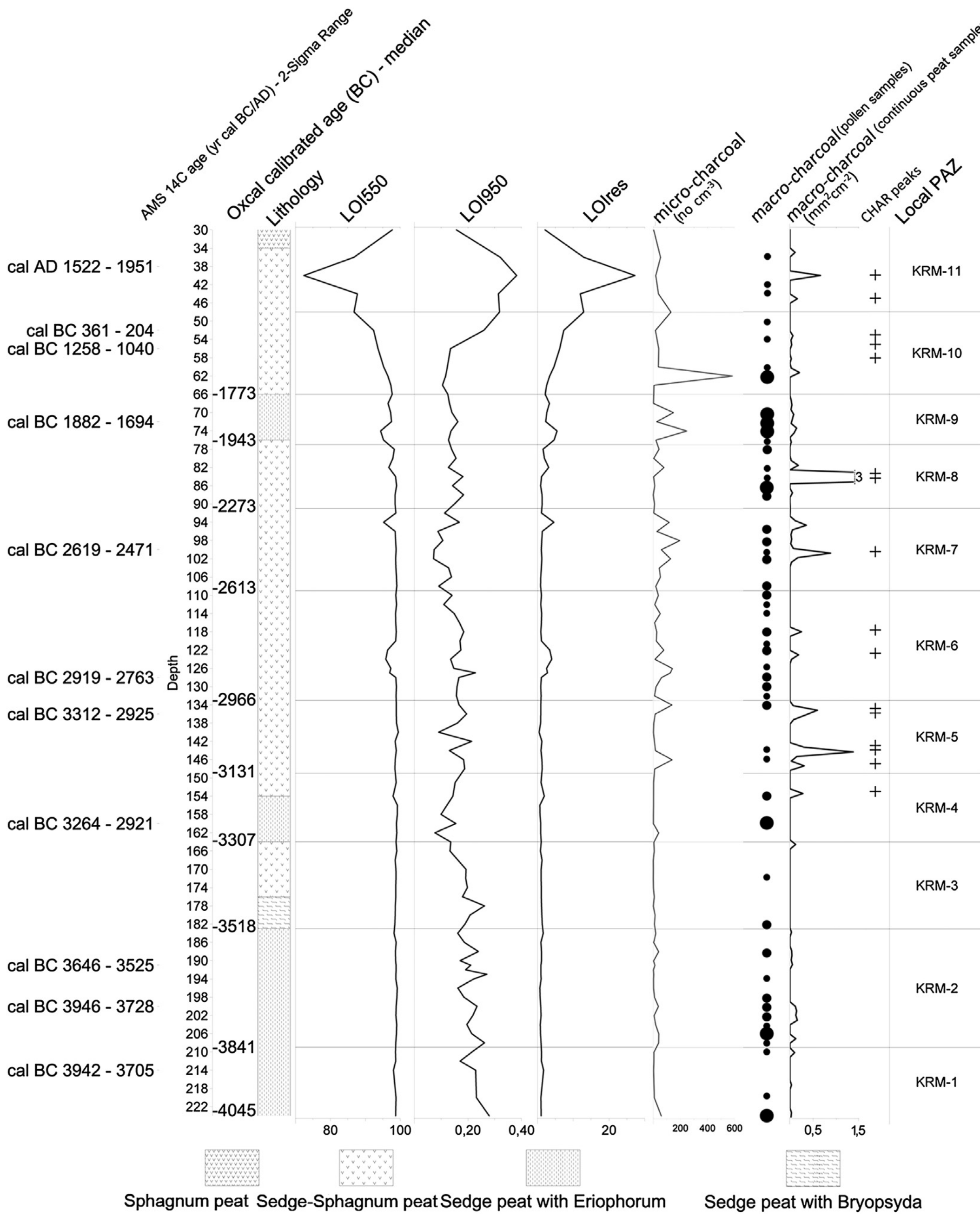

Fig. 4. Loss-on-ignition, micro and macro-charcoal diagram of the core KRM 0.30–2.24 m.

(Andersen, 2010; Holtorf, 2000–2008), and a significant opening of the surrounding area during the Bronze Age (Zich, 1992).

At Krähenberg, we could not detect forest disturbance in the surrounding of the megaliths between approx. 3500 cal. BC and 3100 cal. BC due to the fact that the percentages of Poaceae and *Plantago lanceolata* pollen (up to 3% and 0.7% respectively), were too low to confirm intensive human activity. This suggests that during the majority of the Funnel Beaker Culture period the graves of Krähenberg were embedded in a woodland landscape with only small forest openings.

5.3. Forest recovery in the Middle Neolithic?

Following the short period of forest disturbances around 3500 cal. BC, in the late Early Neolithic, proximate increases of *Tilia* and *Quercus* in the diagram indicate the recovery of forest ecosystems in the surrounding area, between approx. 3500 cal. BC to 3100 cal. BC. Otherwise there is only a slight increase in pollen of Poaceae and anthropogenic indicators like *P. lanceolata* and *Rumex*-type. Andersen (1992) interpreted this phenomenon as a sign of using the trees to provide fodder for livestock husbandry, as pollarding causes high flower and pollen production in the upper parts of the crown of the affected trees. Behre (2008) describes *Tilia* as to be especially sensitive to the effects of human impacts in the landscape. This pollarding usage of Neolithic forests may have existed only locally, and no longer than 500 years (Rickert, 2006). Around 3000 cal. BC, cattle raising based on leaf fodder seems to be no longer in practice (Behre, 2008).

At Krähenberg the changes in the forest composition are detectable. Between approx. 3100–3000 cal. BC the pollen record shows

Table 3
Description of the pollen, loss-on-ignition, micro- and macro-charcoal diagram of the core KRM 0.30–2.24.

LPAZ	Depth [cm]	Pollen spectrum description	Microcharcoal	Macrocharcoal	LOI	cal. BC
11	30–66	Arboreal pollen prevails with 35–65%, and the continuous curve of *Fagus* reaches 5%. The presence of long distance transported pollen of *Pinus* increases up to %. Finally, arboreal pollen declines to 27%. Poaceae values increase up to 60%. *Calluna*, cereals and *Plantago lanceolata* pollen display their highest values.	Only few small signals.	Two CHAR peaks were identified.	Organic matter decreases to 73% of LOI550, carbonate content increased to 0.4% LOI950 and mineral matter mainly mirrors the loss on ignition curves.	
10	48–66	Beginning of a gradual decline in arboreal pollen, in the upper part the percentage of AP declines below 57%. *Alnus* decreases from 35% down to 25%, the continuous curve of *Fagus* pollen reaches from 0.5% to 3%. *Calluna* and Poaceae increase, as well as *Plantago lanceolata* cereal pollen like Cerealia-type undiff., *Avena-Triticum*type, and *Hordeum*-type occur.	Peak followed by three macrocharcoal CHAR peaks, though accumulation is low.	Three macrocharcoal CHAR peaks.	Organic matter decreases continuously to 87% of LOI550, carbonate content increased slightly, up to 0.3%.	from 1780
9	66–76	This is marked by an increase of *Alnus* and a slight dominance of *Corylus* pollen percentages. In the upper part of the zone, *Tilia* pollen declined down to 1%, arboreal pollen decreased down to 70% while values of *Calluna*, Poaceae and ruderal herbs increase. A slight increase of Cerealia-type pollen is detectable.	Microcharcoals peaks.	Only few macrocharcoal signals are present.	Low organic content (95% of LOI550) of sediments.	1940–1780
8	76–91	High values of *Betula*, increase of *Tilia* pollen, while values of AP fluctuate between 75% and 90%. *Calluna* declines up to 1% or disappears. Only one grain of Cerealia-type pollen (unidentified) was observed in the upper part of the zone.	The microcharcoal signal is weak.	Important quantity of charred material with two CHAR peaks identified.	No marked changes.	2280–1940
7	91–109	*Corylus* increases up to 50%. This high value of *Corylus* was coeval with the increase of Poaceae and anthropogenic indicators, as well as an increase of micro and macro-charcoal. In the middle of the zone, the curves of *Tilia* and *Betula* decrease progressively to 1% and 5% respectively.	Increase of micro-charcoal.	Increase of macro-charcoal, one CHAR peak.	No marked changes.	2610–2280
6	109–133	Decrease of *Alnus* down to 20%, elevated values of *Corylus*, grasses and ruderal herbs. The *Fagus* -curve is discontinuous. Anthropogenic indicators like *Plantago lanceolata*, *Rumex*, and *Artemisia* are present in very low values (1%). *Calluna* fluctuates and reaches high values at the transition to *Zone 7*.	Relatively important micro-charcoal accumulation.	The macrocharcoal values are low but still allow the detection of two CHAR peaks.	LOI550-curve shows a first depression.	2970–2610
5	133–149	Absolute *Alnus* maximum, *Alnus* – clumps. *Tilia* declines down to 1%. Non-arboreal pollen (NAP) varies between 7% and 17%, and is dominated by *Calluna*. *Plantago lanceolata* and Poaceae occurred up to 0.5% and 1% respectively.	Accumulation increases, two distinct microcharcoal peaks.	Accumulation increases, several macrocharcoal CHAR peaks.	No marked changes.	3130–2970
4	149–163	*Alnus* reaches a first maximum, up to 47%. *Tilia* decreases from 10% to 2%. A few pollen grains of the *Avena-Triticum*-type were detected. Poaceae continuing with up to 3%. Change in peat composition and an increase of *Sphagnum*-spores up to 40% of the total pollen and spores sum are detected.	Small accumulation observed.	Small accumulation observed, with a first statistically identified CHAR peak.	Lower organic content (50% of LOI550) in middle part of zone.	3300–3130
3	163–183	*Tilia* increases up to 9–12%, Betula up to 20–30% and *Quercus* up to 21%. Pollen of *Plantago lanceolata* and Poaceae has 0.7% and 3% respectively.	No significant evidence.	No significant evidence.	Carbonate content decreased to 0.1% LOI950.	3520–3310
2	183–209	Values of arboreal pollen (AP) fluctuate between 93% and 79%. A slight increase of Poaceae and *Calluna* ca. 3840–3520 cal. BC is accompanied by a conspicuous *Corylus*-peak of up to 66%. *Tilia* decreases to 1% and *Pinus* increase up to 4%. The first record of Cerealia-type (unidentified) in the upper part of the zone.	Signals are low, without identified peaks.	Signals are low, without identified CHAR peaks.	No marked changes.	3840–3520
1	209–224	Arboreal pollen prevails with 90–94% of the total pollen, represented mainly by *Quercus*, *Corylus*, *Tilia*, *Alnus* and *Ulmus* pollen. Decline of *Ulmus* from 11% to 0.6%, and a decrease of Tilia from 16% to 7%. Poaceae with c.1% and *Calluna* with 4–5% occur in comparatively low values.	Virtually absent.	Virtually absent.	98% LOI550 indicates a very high content of organic matter in the peat.	4050–3840

the increase of *Alnus* and a decrease of *Corylus* as well as *Tilia,* with the simultaneous increase of Poaceae. These events could both reflect human activity in the wider area as well as the result of the decrease in local tree canopy. Presence of clumps of *Alnus* pollen grains in the *Zones 4 and 5* indicate that alder pollen rain reflects mainly local vegetation, and thus *Alnus* pollen in the diagram seems to be over represented. Parallelling the increase of *Alnus*, *Sphagnum* spores show high values. This might reflect local wet conditions of the mire development. The cereal curve is scattered, while the continuous curves of Poaceae and anthropogenic indicators like *Plantago lanceolata* and *Rumex acetosa*-type occurred in very low values.

5.4. Evidences for fire events

Macrocharcoal records are defined as providing evidence for local fire occurrences (e.g., Clark et al., 1998; Mooney and Tinner, 2010; Ohlson and Tryterud, 2000), in contrast to microcharcoal records, which can represent the fire occurrences at the regional level (Conedera et al., 2009; Tinner et al., 1998).

In the micro- as well as macrocharcoal record of Krähenberg, in most zones there is evidence for fires (Fig. 4), with a significant increase since 3000 cal. BC. Before that, only weak fire indications are present, the most significant (though not enough so for a CHAR peak) around 3800–3700 cal. BC, during the decline of *Tilia*. The presence of such macrocharcoal records might be related to the occurrence of certain type of fire (e.g. intensive crown forest fire) possibly inducing long distance macrocharcoal transportation (Tinner et al., 2006). This fits in later with the high values of the microcharcoal signal which seems to support the important fire activity at the regional level. However, a good quantity of the macrocharcoals are derived from *Calluna* leaves or even moss leaves, which clearly indicates a fire event on the mire itself. As no distinct black layer was observed in the stratigraphy, we assume that the intensity of these fires on the mire surface was low and did not burn significant parts of the peat.

The first CHAR peak is detected in *Zone 4* appears to indicate local fire events, while the evidence of fires at a regional scale is weak. In the *Zone 5*, between approx. 3100–3000 cal. BC, the micro and macrocharcoal signal appears to synchronously indicate regional and local fire occurrences, with the identification of five CHAR peaks. Between approx. 3000–2600 cal. BC (*Zone 6*) the microcharcoal signals most likely indicate regional fire events, while local fire evidence is very small despite the detection of two CHAR peaks.

The trend to more fire events in the upper part of the record, and especially during *Zones 7–9* (2600–1700 cal. BC) is in accordance to the slight increase of Poaceae and *Plantago lanceolata*. Around 2100 cal. BC a strong macrocharcoal signal occurred with two CHAR peaks, clearly indicating intensive local fire activity. An increase of *Betula* pollen can be interpreted as the spread of this pioneer tree, however in the past a different relationship was identified by Tinner et al. (1999), where *Betula* is identified as fire dependant and *Betula* peaks post date fire outbreaks. It is clear from the pollen diagram that the *Betula* preceded the fire, and then coincides with these peaks (Figs. 3 and 4, LPAZ KRM-8). This could be due to the presence of *Betula* in an open forest structure with fire sensitive fuel, presenting local condition suitable for fire ignition. Therefore fire occurred after the establishment of *Betula*, and not as a consequence of the opening due to fire. Otherwise, the following increase of *Tilia* pollen indicates a new period of slight forest regeneration. Between approx. 2000–1800 cal. BC, the microcharcoal record indicates a higher level of burning, possibly from the larger catchment area, resulting from a general increase of human activities at regional level. Micro and macrocharcoal signals from the Bronze Age (~1800 cal. BC) indicate intensive fire activity.

5.5. Cereal cultivation

Very low signals of cereal pollen cannot confirm the presence of arable fields close to the megalithic graves during the Neolithic period. The under represented value of cereals can be seen as evidence that the area surrounding the megaliths, in spite of some signals of human impact, was not significantly integrated in the agricultural activities of the Neolithic people. Major ecological changes in the local environment are detected from the Bronze Age onward by the decrease in local tree canopy as well as by the higher values of grasses and light-demanding ruderal herbs. Only a few cereal grains were observed. A change of the peat composition of the mire possibly suggests the opening of landscape and the recession of the deciduous forest, combined with signs of clearance and fire events. Lower organic content of sediments samples could have been caused by the input of mineral components into the peat after the forested area surrounding the mire was opened. However, continuous curves of cereals such as *Avena-Triticum*-type and *Hordeum*-type, detectable only from ~1200 cal. BC, are most likely associated with the presence of small scale arable fields in the vicinity. Pollen evidences of *Plantago lanceolata*, *Artemisia*, Chenopodiaceae and high value of Poaceae suggest the onset of the formation of an open agrarian landscape (Bourgeois and Fontijn, 2008; Fokkens, 1999; Kristiansen, 2010) and the creation of the first pastures at Krähenberg in the Bronze Age.

6. Conclusions

High resolution pollen analysis and age–depth modelling using OxCal modelling allow a detailed reconstruction of the vegetation dynamics in the surrounding area of the megaliths during the Neolithic period. Archaeological findings give clear evidence for the presence of people of the Funnel Beaker Culture in the area of Krähenberg. Palaeoecological results have shown that the forest at Krähenberg was opened possibly in connection with the construction of the megaliths around 3500 cal. BC. The following period of forest recovery of about 400 yr cal. leads to the conclusion that during the Funnel Beaker Culture the surrounding area of the megaliths was mainly covered by mixed deciduous forests and the megaliths were not exposed in the landscape. No significant evidence of local fire activity between approx. 3500 cal. BC and 3100 cal. BC was found. A very low occurrence of anthropogenic indicators allows the assumption that the closed surrounding of the megalithic graves was not used during the Funnel Beaker Culture or was used solely as a specialised ritual place around 3500 cal. BC. More intensive human impact with forest disturbance is detectable later, in the period of the Single Grave Culture, followed by a period of forest regeneration and low human impact. The signs of anthropogenic activity in this period are observed but give no reason for the assumption that the surrounding area of the megaliths was used for cereal cultivation. Although anthropogenic forest disturbance and fire events already occurred during the Neolithic period, the intense human impact associated with higher level of burning and arable farming commenced during the Bronze Age, which can be seen as an evidence of a different perception of megalithic graves and cultivated areas in the landscape than in the Neolithic period.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jas.2012.05.043.

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